Modeling the Relationships Between Cortical Surface Reconstruction Methods

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Introduction

Increasingly, brain cartographic methods are being implemented in attempts to create cortical surface reconstructions that are useful and accurate. Cortical surface reconstruction packages are becoming a common tool for visualizing the gray matter (GM) surface, the white matter (WM) surface or the surface midway between the GM and WM. Freeware packages for surface reconstructions include BrainVisa (BV) [1], SureFit/CARET (CT) [2] and FreeSurfer (FS) [3]. Previous research has demonstrated that there are significant differences between cortical surfaces that are produced by different packages when using the same MRI volume [4]. As increasingly more results are published using surface reconstructions, it is imperative that there exist models which allow one to relate or compare results from one package to those results produced by another package.

Methods

High resolution 1.5T, T1-weighted MRI brain scans (0.86mm x 0.86mm x 1.00mm) from 11 subjects (mean age: 26, 5 females, 6 males) obtained in a static force experiment [5] were used to create surface reconstructions from three methods. A typical pipeline performs intensity corrections in the MRI scan, strips the skull, removes the cerebellum, bisects the cerebral hemispheres and creates triangulated surfaces. The amount of user input involved in these processes varies from selecting a few points on a MRI scan to manual editing a surface.

BrainVISA (BV) requires the software operator to identify the right and left hemisphere in addition to specifying the locations of the anterior and posterior commisures. After these points have been visually identified, the data is sent through a fully automated pipeline which processes the data to completion. Automated intensity histogram analysis and the use of "Markovian regularization" results in the binary classification of voxels. Seed growing is used to remove the cerebellum and to identify the proper location to split the two hemispheres, resulting in a Voronoi tessellation. BV creates topologically correct WM surfaces, though its GM surfaces are not always topologically correct with the version available at the time of the study. Very low user input is necessary to operate the BV software package.

Surefit/CARET (CT) produces a surface reconstruction that is midway between the GM and WM, approximating cortical layer 4 (L4). We intensity corrected the MRI data with the Montreal Neurological Institute's N3 algorithm prior to processing. Although CT does not require the data to be intensity corrected, we found that surfaces were easier to reconstruct with CT when they were intensity corrected. CT reconstructs the surface by combining inner and outer boundary maps to generate a smooth map of position along the radial axis. Thresholding the radial position map at an intermediate intensity level generates a segmented volume. Topological errors are corrected through an automated and manual editing process.

FreeSurfer (FS) requires more user input than the other two software applications. Intensity correction and other initial processing is automated. With each hemisphere of the brain that is processed, the lateral ventricle and the basal ganglia must be manually filled. The fornix, the optic nerve and the cerebellum were also removed by manual editing. A combination of manual and automated editing renders topologically correct WM and GM surfaces.

Surface areas of the cortical reconstructions were calculated using in-house software, TopoCV [6]. Volumetric analysis of the GM and the WM were provided by BV and FS. Volumetric results for CT were computed using in-house software. These volume and surface areas were used to develop equations to convert from BV to FS or to CT values for surface area and volume.
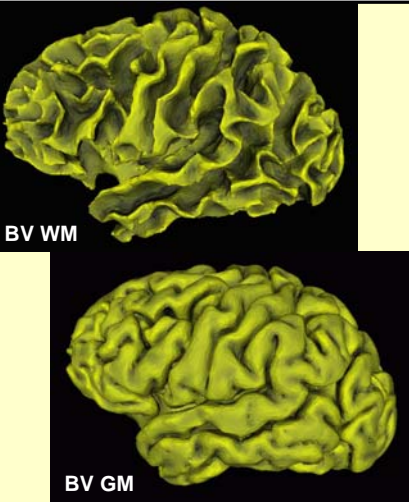
BV WM

BV GM

Conversion Equations

$$\text{FS WM volume} = (1.196)(\text{BV WM volume})$$
$$\text{FS WM surf. area} = (1.343)(\text{BV WM surf. area})$$
$$\text{FS GM volume} = (1.361)(\text{BV GM volume})$$
$$\text{FS WM surf. area} = (1.375)(\text{BV WM surf. area})$$
$$\text{CT L4 volume} = (1.689)(\text{BV GM volume})$$
$$\text{CT L4 surf. area} = (1.127)(\text{BV GM surf. area})$$
$$\text{CT L4 volume} = (1.237)(\text{FS GM volume})$$
$$\text{CT L4 surf. area} = (0.819)(\text{FS GM surf. area})$$

CT L4

RH & LH Surface Area vs. Volume — Surface Area [mm^2] vs. Volume [mm^3]; legend: FS WM, BV WM, FS GM, BV GM, CT L4
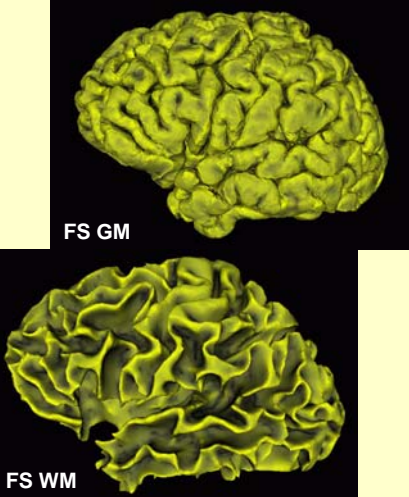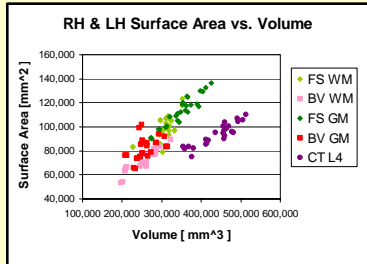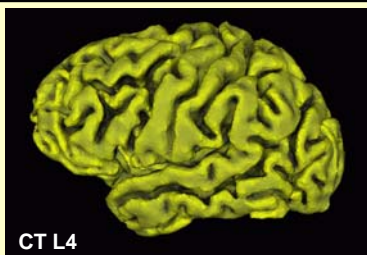

FS GM

FS WM

Figure 1: Surface reconstructions from the same subject exemplify texture and shape differences across methods. Conversion equations between software packages for surface area and volume are presented.

Results

Results for the left hemisphere (LH) surface reconstructions are shown in Figure 1. There is a linear relationship that can be observed between surface area and volume, as indicated in the graph in Figure 1. Furthermore, there is a shift from BV values up and to the right to get comparable FS values. CT volume results are larger than those of the other methods We have developed equations from BV to FS or to CT values for surface area and volume.

Volume: The FS WM mean volume of 320,693 mm³ was significantly larger than the BV WM mean volume of 254,967 mm³ (2 sample t-test, n=11, p=0.001). Likewise, the mean FS GM volume of 346,727 mm³ was larger than the mean BV GM volume of 254,459 mm³ (2 sample test, n=11, p<0.001). The mean GM/WM ratios for FS and BV were 1.089 and 1.002 respectively. The mean volume for CT L4 surfaces was 439,739 mm³ and was large in comparison to the other two methods.

Surface Area: The mean WM surface area of 97,063 mm² for the FS method was larger than the mean BV WM surface area of 72,689 mm² (2 sample t-test, n=11, p<0.001). The FS mean GM surface area 112,934 mm² was larger than the BV GM surface area mean of 82,214 mm² (2 sample t-test, n=11, p<0.001). The CT L4 mean surface area was 93,800 mm² and lies between the mean WM and GM surface areas of FS.

Conclusions

Brain images in Figure 1 exemplify significant variability in the shape of WM surfaces between methods, while the GM surfaces are more consistent in their gyrification. FS tends to have a larger brain rendering than BV as indicated by the larger WM and GM volumes and surface areas. The CT surfaces appear to be good intermediate surfaces between the FS WM and GM surfaces in terms of surface area. The mathematical models we have developed allow one to convert FS surface area and volume results to BV and vice versa. We have developed similar equations for conversions across CT. These conversion equations facilitate the comparison and understanding across studies using one surface reconstruction method versus another.

References

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Acknowledgements

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